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April 12, 2005

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APPLICATION NUMBER: ***60/552,652***
FILING DATE: ***March 12, 2004***
RELATED PCT APPLICATION NUMBER: ***PCT/US05/08372***

Certified by

Jon W. Dudas

Under Secretary of Commerce
for Intellectual Property
and Director of the United States
Patent and Trademark Office

031204 17364 U.S.PTO

PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION under 37 CFR 1.53(c).

22154 U.S. PTO 60/552652 031204

Docket Number:	18388-08963

INVENTOR(s)

Given Name (first and middle [if any])	Family Name or Surname	Residence (City And Either State Or Foreign Country)
Steven Porter	**Hotelling**	**San Jose, California**
Lex	**Bayer**	**Menlo Park, California**
Brian R.	**Land**	**Redwood City, California**

☐ Additional inventors are being named on ___ separately numbered sheets attached hereto.

TITLE OF THE INVENTION (500 characters max.)

DUAL AXIS VIBRATORY RATE GYROSCOPE

CORRESPONDENCE ADDRESS

Direct all correspondence to:

☒ Customer Number **00758**

ENCLOSED APPLICATION PARTS (check all that apply)

☒ Specification	*No. of Pages:* 7	☒ Return Postcard	
☒ Drawing(s)	*No.of Sheets:* 10	☐ CD(s), Number	
☐ Application Data Sheet See 37 CFR 1.76		☐ Other *(specify)*	

METHOD OF PAYMENT (check all that apply)

☐ Applicant claims small entity status. See 37 CFR 1.27

☒ Fee Transmittal Form Enclosed (in duplicate) ☒ Check Enclosed

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

☒ No.

☐ Yes, the name of the U.S. Government Agency and the Government contract number are: ______

SIGNATURE OF ATTORNEY OR AGENT

Signature:	A. C. Smith		
Attorney/Reg. No.:	Albert C. Smith, Reg. No. 20,355	Dated:	3/12/04

CERTIFICATE OF MAILING

I hereby certify that this correspondence is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service pursuant to 37 CFR 1.10 in an envelope addressed to: Mail Stop Provisional Patent Application, Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450 on the date shown below.

Signature:	A. C. Smith		
Typed or Printed Name:	**Albert C. Smith**	Dated:	3/12/04
Express Mail Mailing Number:	**EV 442673967 US**		

USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

FEE TRANSMITTAL for FY 2004

Patent fees are subject to annual revision.

☐ Applicant claims small entity status. See 37 CFR 1.27

TOTAL AMOUNT OF PAYMENT	($) 160

Complete if Known	
Application Number	Not Yet Known
Filing Date	March 12, 2004
First Named Inventor	Steven Porter Hotelling
Examiner Name	Not Yet Known
Art Unit	Not Yet Known
Attorney Docket No.	18388-08963

METHOD OF PAYMENT (check all that apply)

☒ Check ☐ Credit Card ☐ Money Order ☐ Other ☐ None
☐ Deposit Account:

Deposit Account Number: 19-2555

Deposit Account Name: Fenwick & West LLP

The Commissioner is authorized to: *(check all that apply)*

☐ Charge fee(s) indicated below ☒ Credit any overpayments

☒ Charge all required fee(s) or any underpayment of fee(s) due under 37 CFR §1.16 or §1.17 during the pendency of this application

☐ Charge fee(s) indicated below, except for the filing fee

to the above-identified deposit account.

FEE CALCULATION

1. BASIC FILING FEE

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
1001	770	2001	385	Utility filing fee	
1002	340	2002	170	Design filing fee	
1003	530	2003	265	Plant filing fee	
1004	770	2004	385	Reissue filing fee	
1005	180	2005	80	Provisional filing fee	160

SUBTOTAL (1) ($) 160

2. EXTRA CLAIM FEES FOR UTILITY AND REISSUE

		Extra Claims		Fee from below		Fee Paid
Total Claims	-20** =		X		=	00
Independent Claims	-3** =		X		=	00
Multiple Dependent					=	00

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description
1202	18	2202	9	Claims in excess of 20
1201	86	2201	43	Independent claims in excess of 3
1203	290	2203	145	Multiple dependent claim, if not paid
1204	86	2204	43	**Reissue independent claims over original patent
1205	18	2205	9	**Reissue claims in excess of 20 and over original patent

SUBTOTAL (2) ($) .00

**or number previously paid, if greater; For Reissues, see above

FEE CALCULATION (continued)

3. ADDITIONAL FEES

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
1051	130	2051	65	Surcharge - late filing fee or oath	
1052	50	2052	25	Surcharge - late provisional filing fee or cover sheet	
1053	130	1053	130	Non-English specification	
1812	2,520	1812	2,520	For filing a request for *ex parte* reexamination	
1804	920*	1804	920*	Requesting publication of SIR prior to Examiner action	
1805	1,840*	1805	1,840*	Requesting publication of SIR after Examiner action	
1251	110	2251	55	Extension for reply within first month	
1252	420	2252	210	Extension for reply within second month	
1253	950	2253	475	Extension for reply within third month	
1254	1,480	2254	740	Extension for reply within fourth month	
1255	2,010	2255	1,005	Extension for reply within fifth month	
1401	330	2401	165	Notice of Appeal	
1402	330	2402	165	Filing a brief in support of an appeal	
1403	290	2403	145	Request for oral hearing	
1451	1,510	1451	1,510	Petition to institute a public use proceeding	
1452	110	2452	55	Petition to revive - unavoidable	
1453	1,330	2453	665	Petition to revive - unintentional	
1501	1,330	2501	665	Utility issue fee (or reissue)	
1502	480	2502	240	Design issue fee	
1503	640	2503	320	Plant issue fee	
1460	130	1460	130	Petitions to the Commissioner	
1807	50	1807	50	Processing fee under 37 CFR 1.17(g)	
1806	180	1806	180	Submission of Information Disclosure Stmt	
8021	40	8021	40	Recording each patent assignment per property (times number of properties)	
1809	770	2809	385	Filing a submission after final rejection (37 CFR 1.129(a))	
1810	770	2810	385	For each additional invention to be examined (37 CFR 1.129(b))	
1801	770	2801	385	Request for Continued Examination (RCE)	
1802	900	1802	900	Request for expedited examination of a design application	

Other fee (specify) ____________________

SUBTOTAL (3) ($) .00

*Reduced by Basic Filing Fee Paid

SUBMITTED BY				Complete (if applicable)
Name (Print/Type)	Albert C. Smith	Registration No. (Attorney/Agent)	20,355	Telephone (650) 335-7296
Signature	A.C. Smith	Date	3/12/04	

DUAL AXIS VIBRATORY RATE GYRASCOPE

Parameter	MG3	Improvement
Vibrating Structure	1 x Etched 6 fold symmetric Beam	Cheaper, Smaller
InPhase Signal Error Correction	Digital subtraction	Easier to manufacture
Signal Transmition to Vibrating Structure	Helical Coil Springs X 4	Easier to manufacture
Output	Digital (serial interface)	Fully Integrated, no need for additional ADCs
Vibration Isolation	Helical Coil Springs X 4	Easier to manufacture
Signal-to-Noise and Bandwidth	Configurable through serial interface	Wider range of applications
Full Scale Rate	1000 deg/sec	Wider range of applications

List of Drawings:

Figure 1: Shows an isometric assembled and exploded view of the Vibratory Structure.
Figure 2: Shows isometric and plan views of several modes shapes of the Vibratory Structure.
Figure 3: Shows an isometric view of the Beam Assembly
Figure 4: Shows an isometric assembled and exploded view of the Signal PCB
Figure 5: Shows an isometric assembled and exploded view of the Drive Side Assembly
Figure 6: Shows an isometric assembled and exploded view of the Sense Side Assembly
Figure 7: Shows an isometric assembled and exploded view of the Suspended Assembly
Figure 8: Shows an isometric assembled and exploded view of the Base Assembly
Figure 9: Shows an isometric assembled and exploded view of the Complete Assembly
Figure 10: Shows a block diagram representation of the top level ASIC architecture

Features and Advantages

1) Vibratory element: Geometry, symmetry and structure of beam allows 1 beam structure (and a single frequency) to be used for sensing rate about two axes. Structure also allows for flat coil assemblies to detect motion. Structure can be manufactured by economical production process (chemical etching).
State of the Art: Many dual axis gyroscopes employ two vibratory structures – one for each axis. Some dual axis gyroscopes do use a single beam structure, but these structures are of different geometry and require expensive manufacturing procedures.
2) Integrated A/D converters: Integrating A/D converts with the sensor allows sensor to output data in a convenient digital format.
State of the Art: Most gyroscopes are fully analog and usually require large off chip capacitors required for analog filtering, as well as conformal coating of these capacitors.
3) Digital Trimming of Error Sources: Various registers on chip allow each sensor to have its error signals minimized during a factory calibration procedure.
State of the Art: These errors are mechanically trimmed by grinding the beam or realigning the transducers.
4) Programmable Bandwidth: Sampling and digital filtering processes are user configurable and allow for the user to essentially program the bandwidth of the sensor by simply writing to a control register.
State of the Art: Some gyroscopes do allow the user to set the bandwidth by adjusting external components such as resistors and capacitors.
5) Dual purpose Suspension System: Springs are used both as an isolating structure and to pass electrical signals to the components of the sensor.
State of the Art: Thin, fragile leads are used to convey electrical signals, some type of beam/damper assembly is used for vibration isolation.
6) Timing Synchronization: All data conversions, phase references, and electrical processes are timed according to the natural resonant frequency of the vibratory element. This allows for various benefits in signal noise, and error matching (tracking) over wide operation conditions.
Sate of the Art: Timing performed in analog domain

Description of the Preferred Embodiment:

Introduction:

The sensor operates in a similar manner to a Tuning Fork Gyroscope. The fundamental principle entails vibrating two proof masses with equal amplitude but in opposite directions. When rotated about an axis orthogonal to direction of forced vibration, the Coriolis force produces an orthogonal vibration which is detected by transducers, and is proportional to angular rate [$F_{Coriolis} = -2 m (\omega \times v)$].

First the mechanical parts and assembly will be described, and then the signal processing, control and system level interactions.

Mechanical parts and Assembly:

The key element of the sensor is the Vibratory Structure. Referring to Figure 1, the Vibratory Structure is made up of a Beam Element, 2 Magnet Holders and 2 Magnets. The Beam Element is of a hexagon shape and composed of several winding serpentine beam lengths. The beam is designed to be 6 (or more) fold axially symmetric. The beam is manufactured by chemical etching, fine blanking, stamping or electro-discharge machining a sheet of such metal as elinvar, stainless steel, beryllium copper, spring steel or other suitable alloy. Alternatively, quartz or silicon may be used to form the beam shape through conventional photolithographic etching processes. Physical vapor deposition processes, such as sputtering, may also be used to produce the desired beam shape. It is desirable that the material of the Beam Element maintain a constant modulus of elasticity over temperature so that the vibration frequency remains suitably constant over the operating temperature of the sensor. The material should be homogenous and the tolerances of the part should be such as to maximize the symmetry between serpentine beam lengths in order create symmetric elastic spring properties in the various serpentine beam lengths, which is required to minimize vibration trajectory misalignment errors.
Three serpentines beam lengths are connected two one of the magnet holders, while three other serpentines are connected to the other magnet holder. This allows the magnet holders to move freely with respect to each other. The Magnet Holders are formed by conventional means such as are screw machining, metal injection molding, or casting a non magnetic material, such as certain stainless steels. The Magnet Holders are attached to the Beam Element by welding, brazing, mechanical fastening, adhesive bonding, or soldering. Two cylindrical permanent magnets are fixed inside the magnet holders with adhesive, mechanical fastening, or magnetic self attraction. The remaining 6 serpentines are connected to a fixed reference (the Mount plate).

Referring to Figure 2, the design of the beam is such that it allows the two Magnets (and Magnet Holders) to vibrate along the X-axis in a counter phase mode, which we will call Drive Mode. The vibratory structure has a further resonant mode, the Sense Mode, which is close in frequency to Drive Mode (to attain a magnification effect), and allows the 2 Magnets to vibrate in any direction in the ZY plane. The 6 fold symmetry of the beam is necessary to allow motion

of the Magnets in any direction in the ZY plane so that two axes of motion can be detected – specifically motion along the Y axis, and motion along the Z axis. The 6 fold symmetry is also necessary to ensure that the error in the Drive Mode trajectory (motion not along the X-axis) is minimized. The vibratory structure is further designed such that other modes are distant in frequency from the Sense and Drive Modes in order to minimize cross coupling effects. An example is the In Phase motion, which is significantly lower in frequency than Drive Mode because of lengths of the 6 mounting serpentine beams.

Figure 3 shows the Beam Assembly. The Beam Assembly is comprised of the Vibratory Structure which is attached to the Mount Plate by welding, brazing, soldering, adhesive bonding, or mechanically fastening the ends of the 6 serpentine beam lengths to protrusions of the Mount Plate. The Mount Plate is designed such that it allows the Vibratory Structure enough physical space to allow the Beam Element to vibrate unobstructed. The metallic Mount Plate is made by stamping, casting, or metal injection molding.

Figure 4 shows the Signal PCB (perforated circuit board). Attached to the Signal PCB are various electronic components. A capacitive Shield Plate is attached to the Signal PCB by soldering, welding, or brazing. The Shield Plate is used to prevent capacitive coupling between the Sense Coils and the various traces and pins on the Signal PCB. The capacitive Shield Plate is a made from an electrically conducting, but also non-magnetic material, such as phosphor bronze, and can be formed through conventional means such as stamping, metal injection molding, or casting. The AGC Coil is attached to the back side of the Signal PCB with adhesive or mechanical fastening. The AGC Coil (and all subsequently mentioned coils) is manufactured by winding insulated electrically conductive wire, such as copper, around a spindle which is later removed. Coils can also be formed by spiraling traces on several PCB layers to generate a coil structure or by depositing metal films onto a substrate and then etching coil turns with photolithographic methods. Two curved Pins (extruded conductive metal, such as phosphor bronze) are also attached to the PCB.

Figure 5 shows the Drive Side Assembly. The Drive Side Assembly is designed to locate the Drive Coil relative to the Vibratory Structure. The Drive Side Assembly consists of a plastic injection molded part, the Drive Mold, which incorporates a location feature for the Drive Coil. The Drive Coil is attached with adhesive, mechanical fastening, heat staking or ultrasonic welding. A magnetically permeable (such as Iron) plate is attached to the rear of the mold. This plate is used to help align the magnetic field (flux lines) generated by the two Magnets of the Beam Assembly so as to maximize the ability of the various coil transducers to detect motion of the Magnets. Several pins are attached to the Drive Mold and are used to carry electrical signals from Drive Side Assembly to the SignalPCB.

A similar arrangement makes up the Sense Side Assembly, as shown in Figure 6. However, unlike the Drive Side Assembly, instead of a Drive Coil, the Sense Mold holds 2 pairs of Sense Coils. The two sets of Sense Coils are positioned at 90 degrees to each other, and will be later assembled in close proximity to one of the Magnet of the Vibratory Structure. These coils are used to detect rotation about the Y, and Z axes. Each set of coils are connected with opposite polarity (wound in opposite directions), such that the majority of motion along the X axis (Drive

Mode vibrations) will not be detected by these coils, whereas motion about the Y, or Z axis respectively, will be detected (sense Mode vibration).

Figure 7 shows the Suspended Assembly. The Drive Side Assembly is attached to the Beam Assembly (Mount Plate tangs) by soldering, welding, brazing or mechanical fastening. The Beam Assembly is further attached to the Sense Side Assembly, in a similar manner to form a compact integrated assembly, which positions the Drive Coil in close proximity to one of the Magnets of the vibratory structure, and the AGC and Sense Coils in close proximity to the other Magnet. The various cross connecting pins are connected (soldered) into the Signal PCB to establish electrical routes through the Suspended Assembly.

Figure 8 shows the Base Assembly. The Base assembly consists of a plastic injection molded part, the Base Mold, which has 4 Pins attached to it. The Belly Plate which is a conducting metallic part made by conventional means such as stamping, casting or Metal injection molding, is attached to the Base Mold by adhesively bonding, heat staking, ultra-sonically welding, or mechanically fastening. A Gasket, molded out of rubber, such as Silicon, is inserted between the Base Mold and Belly Plate as shown. Helical Springs are connected to the pins by soldering, welding, brazing, or mechanical fastening. The Helical Springs are made from electrically conducting material that is wound into a helical spiral shape.

Figure 9 shows the Complete Assembly. The Suspended Assembly is positioned onto the 4 Helical Springs, and attached by soldered, welding, brazing or mechanical fastening. The purposes of the helical springs are two fold: firstly, the springs allow electrical signals to be passed from the Pins in the Base Mold to the Signal PCB; secondly, the springs provide vibratory isolation between the suspended assembly and the base of the unit. This isolation is necessary in order to prevent unwanted vibrations (linear acceleration, mass mismatch effects) from being detected.
Lastly, a Can is then attached to the Belly Plate of the Base Assembly to form a closed container that is used to shield the sensor from undesired interference sources, such as Radio Frequencies (RF) and external magnetic fields. The Gasket of the Base Assembly forms a seal against the can so as to prevent moisture from entering the assembly.

Signal Processing, Control and System Level Interactions:

The Signal PCB contains an ASIC (Application Specific Integrated Circuit), and EEPROM (Erasable Programmable Memory) and other discrete components such as capacitors and resistors. The ASIC performs all the necessary signal processing and control required for the sensor to perform.

Please refer to Figure 10 for an architectural view of the ASIC.

The various coils in the assembly are used as transducers which are able detect or induce motion of the Magnets. The Vibratory Structure is excited at its natural resonant frequency by the sending current through the Drive Coil, which is situated close to one of the Magnets attached to the vibratory structure. This produces a corresponding sine wave signals generated on the AGC

Coil, which is located close to the other Magnet. The amplitude of this sine wave represents the physical amplitude of vibration of the magnets. This signal on the AGC coil is amplified and is used to establish a self correcting feedback loop (automatic gain control loop) which adjusts the level of current supplied to the Drive coil so as to maintain a given level of vibratory amplitude.

When the sensor is rotated, low level voltage signals are generated on the Sense Coils by the Coriolis Effect. The sense signals have a 90 degree phase reference (cosine signal) relative to the AGC signal, since Sense Vibrations occur at the Drive Mode Frequency and are therefore off resonance. The ASIC uses a digital phase lock loop (PLL) in order to phase lock to the AGC signal and generate a fixed 90 degree phase shift.. This is accomplished by using a high frequency oscillator which is divided down to a frequency that matches the natural vibration frequency of the Vibratory Structure and locked to a phase reference (such as the zero crossing point) of the AGC signal.

Various error signals on the sense channels are compensated for by means of programmable digital to analog converters (DACs) that add or subtracted scaled signals to the sense channels in order to correct for these errors. Error sources include a large In Phase (Drive Mode) signal, a DC offset signal from the pre-amplifiers, and a Cross Axis signal (some amount of motion about the Y axis will be detected along the Z axis).

Once these error signals are electronically removed, the sense signals are demodulated (the desired sense signal has a 90 degrees phase relationship to the AGC signal) which allows the sense signal to be fully extracted while parasitic vibrations are cancelled. Since the desired signal is of a cosine nature, in order to detect the signal amplitude, the signals are also rectified. The demodulated and rectified signals are then converted to digital levels through the use of conventional analog-digital converts, such as a Sigma Delta Converter type. Digital filtering is further performed in order to remove the unwanted high-frequency components present on the signals. The timing of the ADC is synchronous with the vibration frequency of the Vibratory Structure. This improves signal to noise of the signal by further removing certain error sources, such as In Phase (Drive Mode) signals still present on the signal and harmonics created by demodulation. The sense signals are then scaled in order to account for unit to unit variations, so that the rate output will be consistent across all units.

The results of each ADC conversion are accumulated in a register on the ASIC. The number of accumulated conversions is set by a user configurable control register. By accumulating several samples, the sense signals are averaged which improves the ratio of signal to noise on the signal. Furthermore, by allowing the user to set the number of samples that are averaged, the user is capable of controlling the effective bandwidth of the sensor.

The ASIC further has conventional temperature sensor and voltage level detectors which are fed through ADCs so that the temperature of the sensor, as well as the supply voltage can be reported. These values are need for higher order error correction for temperature and voltage dependant phenomena.

The ASIC communicates with an external microcontroller or microprocessor using a serial 2 wire interface, such as Philips' I2C interface. Both the ASIC and the EEPROM act as slave devices. During factory calibration, many of the error signals are measured and the appropriate scaling factors stored in the EEPROM. During normal operation, an external microprocessor or microcontroller reads in the stored calibration values from the EEPROM and then writes them to RAM on the ASIC. The ASIC uses these stored values in RAM to set the appropriate DAC levels used for performing the error corrections discussed above. The 2 wire interface is used to conserve on the number of connections required between the external package and the suspended assembly.

Lastly, the ASIC includes on chip voltage regulators which are used to maintain a constant voltage supply reference to the various block of the ASIC.

Express Mail Label No. EV 442673967US
Title: Dual Axis Vibratory Rate Gyroscope
Inventor(s): Steven P. Hotelling, et al.
Atty. Docket No.: 18388-08963

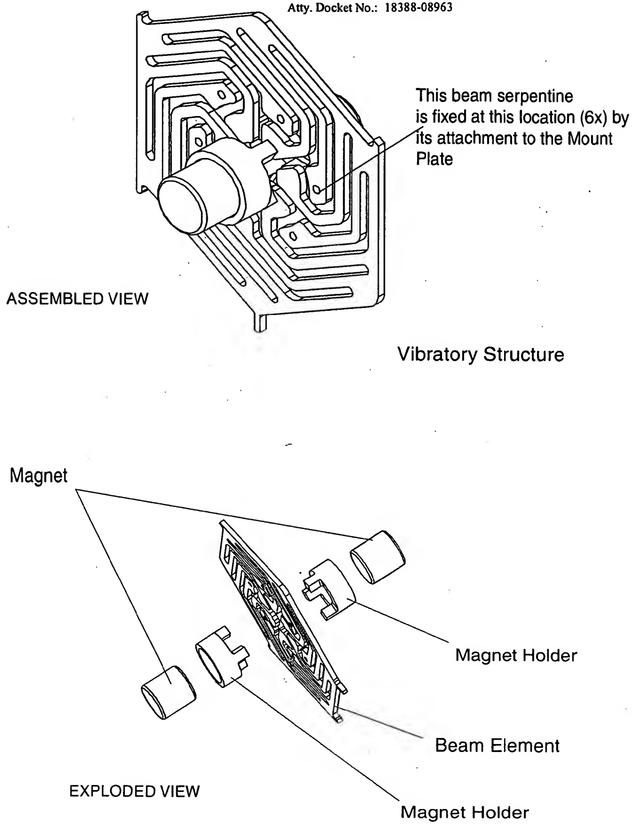
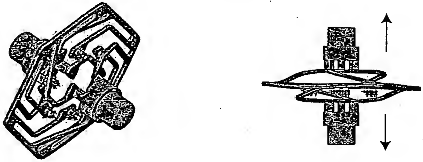
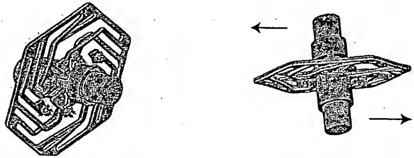


FIGURE 1

Drive Mode: Counter Phase motion - both magnets move along X - direction, but magnets move in opposite directions



Sense Mode: Magnets move in YZ plane, in opposire directions



In Phse Mode : In Phase Motion (both magnets move along X direction) in same direction

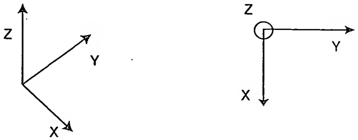


Figure 2

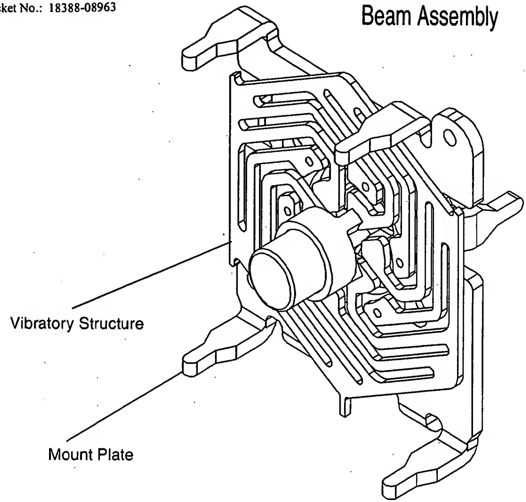


Figure 3

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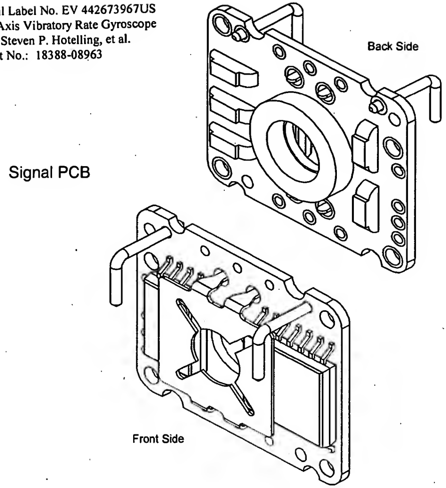
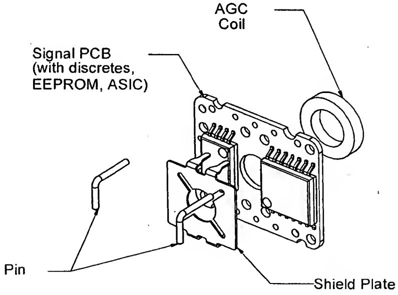
Atty. Docket No.: 18388-08963



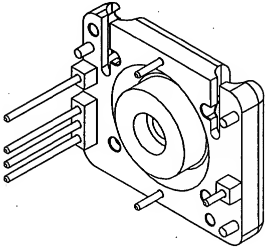
ASSEMBLED VIEWS



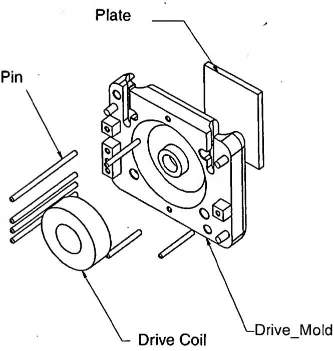
EXPLODED VIEW

Figure 4

Drive Side Assembly



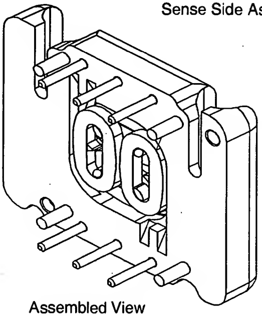
Assembled View



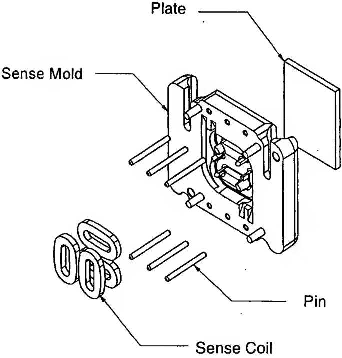
Exploded View

Figure 5

Sense Side Assembly



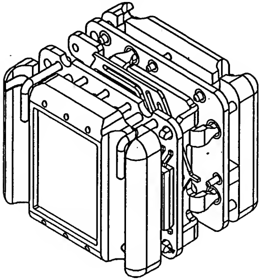
Assembled View



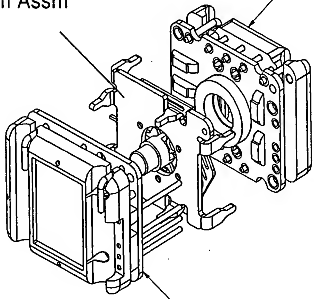
Exploded View

Figure 6

Suspended Assembly



Assembled View



EXPLODED VIEW

Figure 7

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Title: Dual Axis Vibratory Rate Gyroscope
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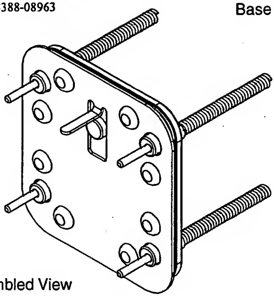
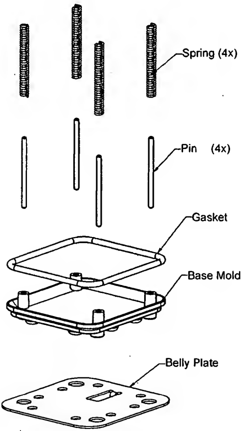
Atty. Docket No.: 18388-08963

Base Assembly



Assembled View



EXPLODED VIEW

Figure 8

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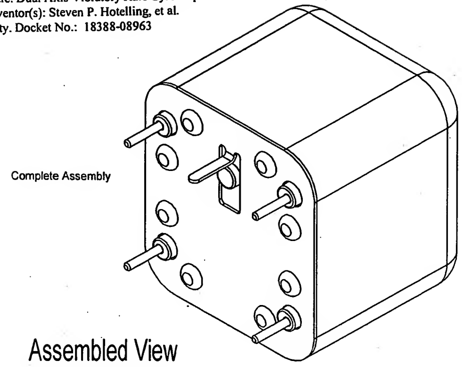
Inventor(s): Steven P. Hotelling, et al.
Atty. Docket No.: 18388-08963



Assembled View

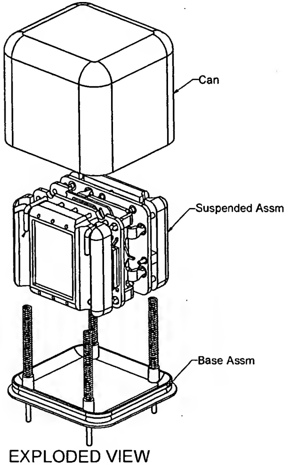


Figure 9

EXPLODED VIEW

Express Mail Label No. EV 442673967US
Title: Dual Axis Vibratory Rate Gyroscope
Inventor(s): Steven P. Hotelling, et al.
Atty. Docket No.: 18388-08963

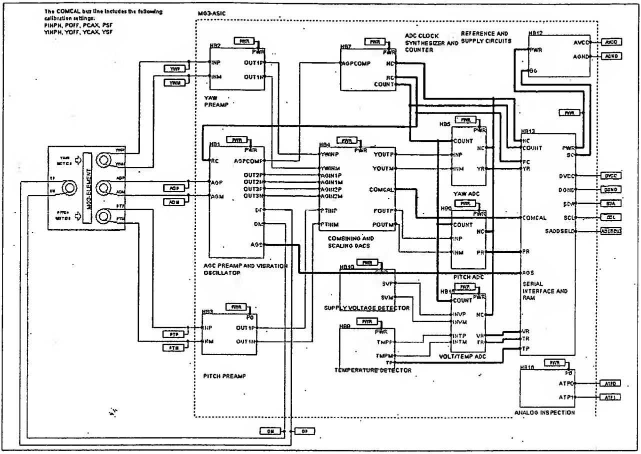


Figure 10